

Winter Vehicle Emissions in Yellowstone National Park

Gary Bishop, Dan Burgard,
Tom Dalton, and Don Stedman
Department of Chemistry
University of Denver
Denver, CO

John D. Ray
Atmospheric Chemist
Air Resources Division
National Park Service
Denver, CO



Snowmobiles
Remote Sensing



Snow coaches
Exhaust measurements

Presentation Topics

- ☐ **Methods for measuring emissions under real use conditions**
- ☐ **Verification of emission reductions.**
- ☐ **Comparison of over-snow vehicles**

Snow Coach Emissions Method



Analyzer for CO, HC, CO₂, NO, O₂, engine parameters, and GPS

On-board emission measurements with Clean Air Tech. Inc. Universal Montana portable monitoring system. Real-time analyzers use NDIR and electrochem cells. Dual detection cells.

Zero and calibration checks. Certified calibration gases used from gas cylinder.



Probe into exhaust pipe.

Heated sample line into van to analyzer.

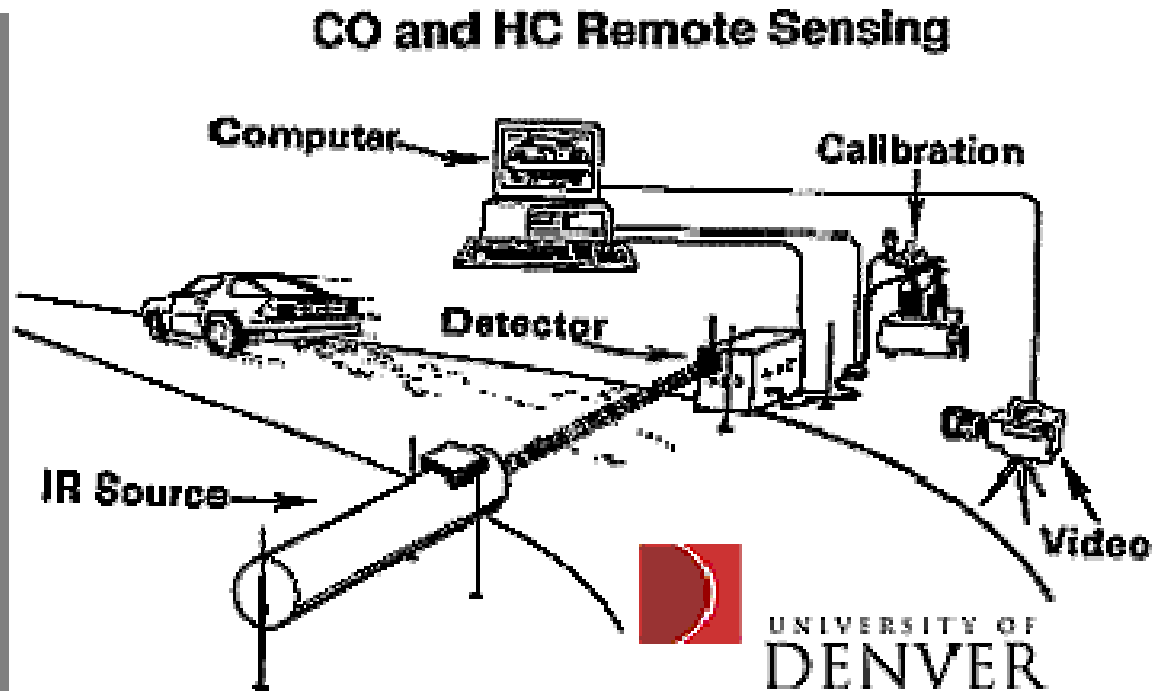
Multi-gas measurements: CO, CO₂, HC, NO, O₂, PM
Engine parameters and GPS

Reference:

Vojtisek-Lom, M.; Allsop, J. E. *Development of Heavy-Duty Diesel Portable, On-Board Mass Exhaust Emissions Monitoring System with Nox, CO₂ and Qualitative PM Capabilities*; **Soc. Auto. Eng.** 2001-01-3641, 2001.

Clean Air Technologies, Inc.: <http://test.cleanairt.com/index.aspx>

Snowmobile Emissions Method



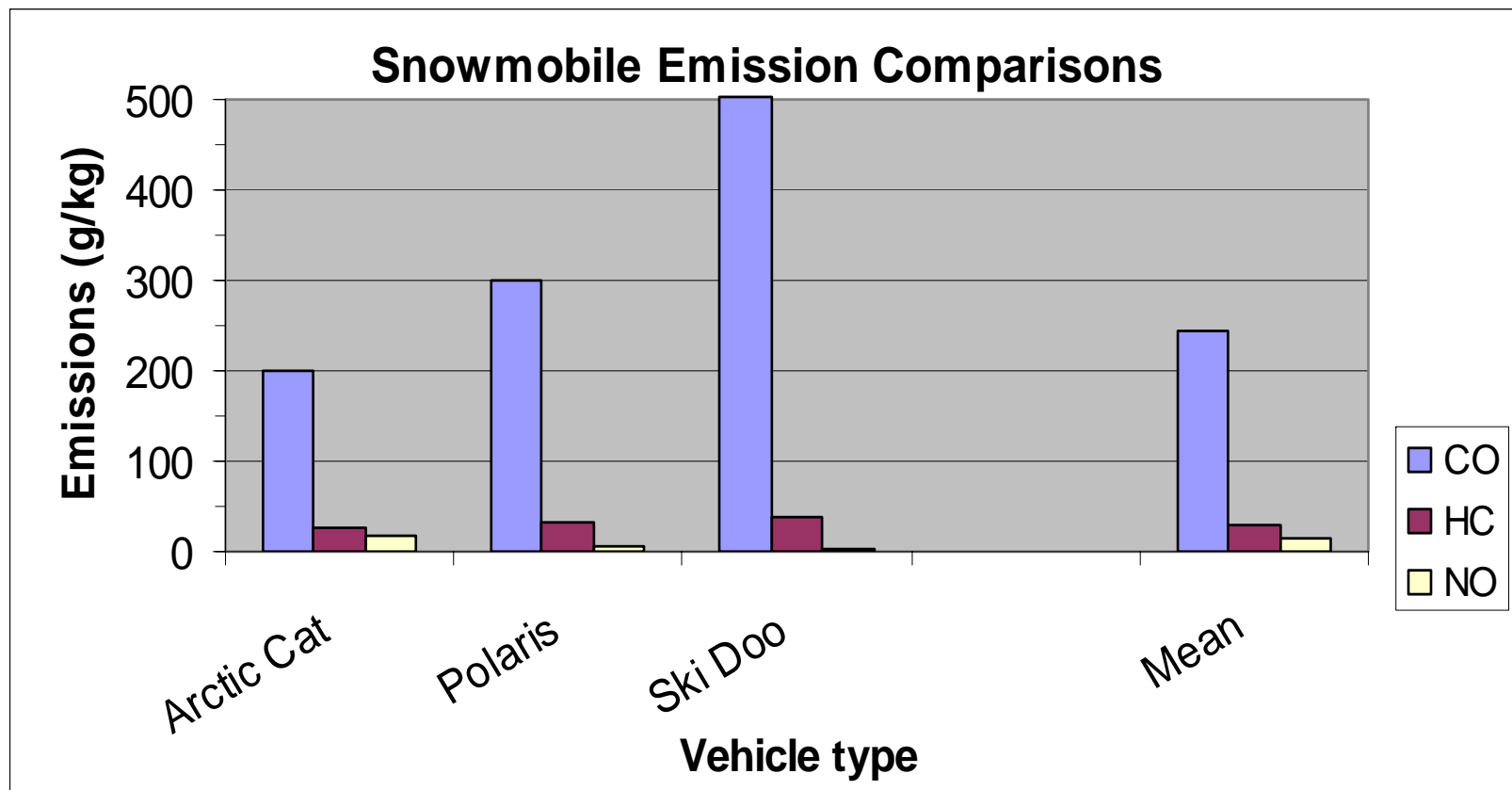
References:

[Snowmobile Contributions to Mobile Source Emissions in Yellowstone National Park](#), G.A. Bishop, J.A. Morris, D.H. Stedman, **Environ. Sci. Technol.**, 35:2874-2881, 2001.

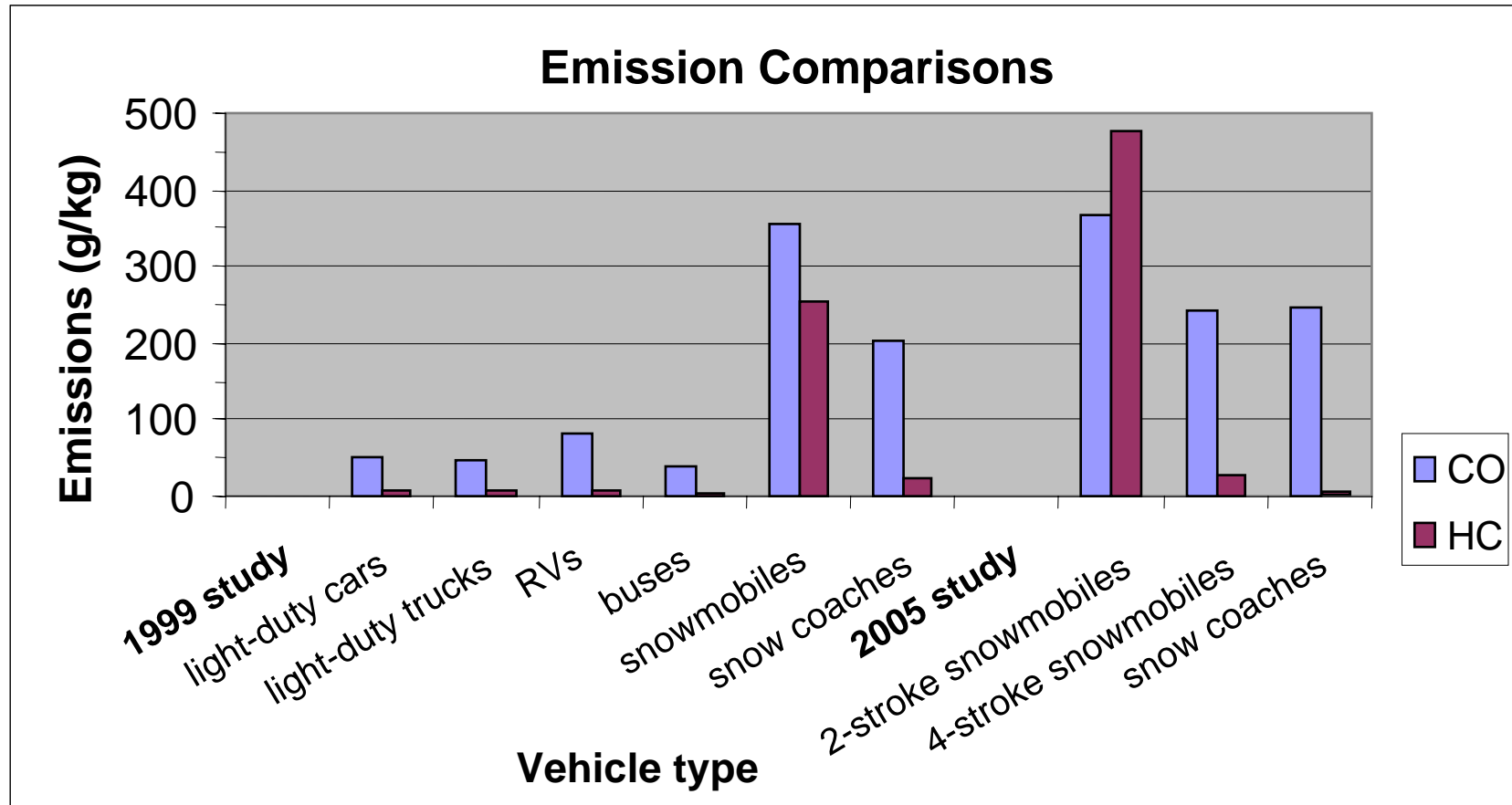
University of Denver: <http://www.feet.biochem.du.edu/index.html>

2005 Study Emissions Results

	gCO/kg	std err	gHC/kg	std err	gNO/kg	std err
2-stroke snowmobiles	366	35	478	25	- -	
4-stroke snowmobiles	243	6	28	2	15	0.5
snow coaches	245	55	1.5	4.5	4.4	1.1

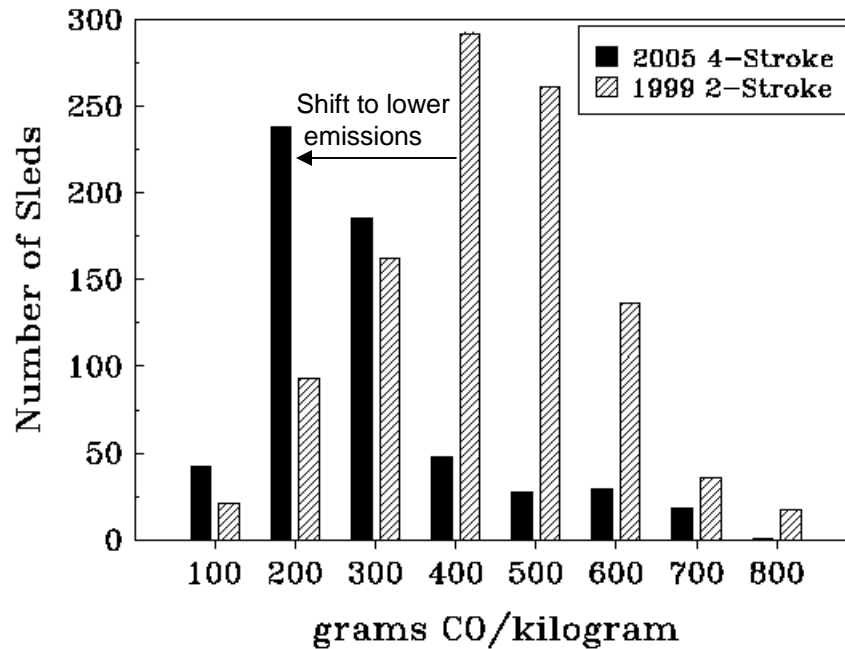


Comparisons with Previous Measurements



Emissions from winter vehicles are higher for both snowmobiles and snowcoaches than for any of the summer-time wheeled vehicles.

Snowmobile Emission Histograms

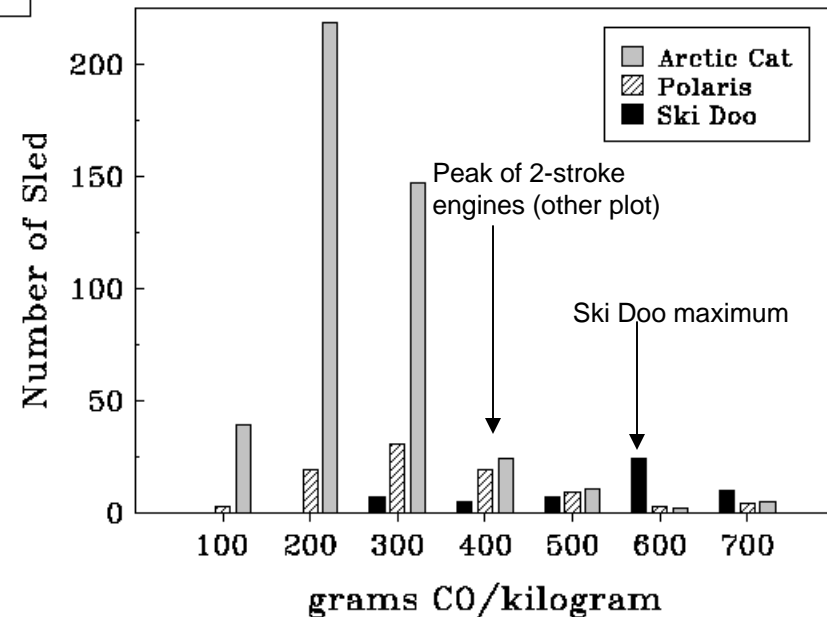


Histograms for each brand of 4-stroke snowmobile of CO emissions.

Ski Doo maximum is much higher CO. It is higher than the peak CO emissions in 2-stroke engines. It is responsible for the observed tailing to higher CO emissions.

Histogram of snowmobile emissions by engine type.

4-stroke engines shift the emissions to lower CO. There is more tailing to high values in the 4-stroke snowmobiles



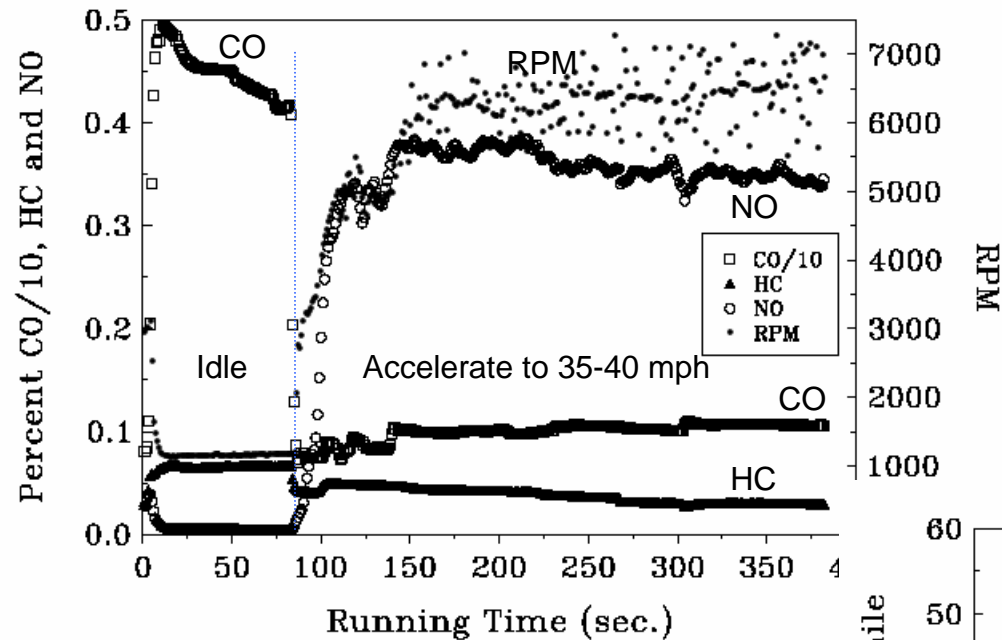
Snowmobile Direct Emission Measurements



Direct emission monitor mounted on Arctic Cat 4-stroke snowmobile. 13 minutes of data: 8 min. at idle; 5 min. driving.

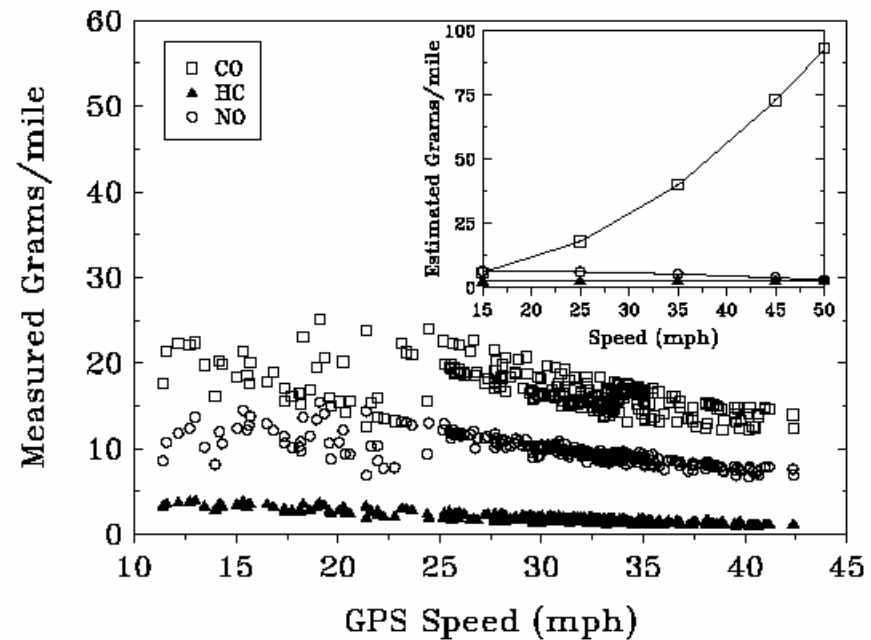
		Direct measurement		Remote sensing
		Idle	Cruise	Mild acceleration
CO	gCO/kg	508	140	201
	g/mi	--	17	31
HC	gHC/kg	29	16	26
	g/mi	--	1.9	4
NO	gNO/kg	0.7	51	51
	g/mi	--	9.7	2.8

Snowmobile Direct Emission Measurements



Snowmobile CO emissions are highest at idle for the Arctic Cat and decrease at higher speeds.

Snowmobile CO emissions did not increase with speed as predicted by the Southwest Institute dynamometer tests (inset).



Snowmobile at the Entrance

A difference in emissions was noted between the lead guide sleds and the client sleds.

		CO	HC	NO
Make	Use	gCO/kg	gHC/kg	gNO/kg
Arctic Cat	Guide	328	28	12.5
	Client	186	26	19.4
Polaris	Guide	362	53	4.1
	Client	289	28	6.4
Ski Doo	Guide	527	70	1.3
	Client	492	28	1.7

- Created tailing in histogram at higher emission levels.
- Appears to be due to guides turning off their snowmobiles at the entrance.
- Bias to slightly higher emissions levels than during cruise mode.

Guide to Snow Coaches



NPS diesel conversion van with Mat-trax



Snow Buster conversion van

Guide to Snow Coaches



Bombardier with carbureted engine



Measured:

Diesel van	Mat-trax	1
Gasoline van	Snow Buster	4
Gasoline van	Mat-trax	2
Bombardier	tracks/skis	2

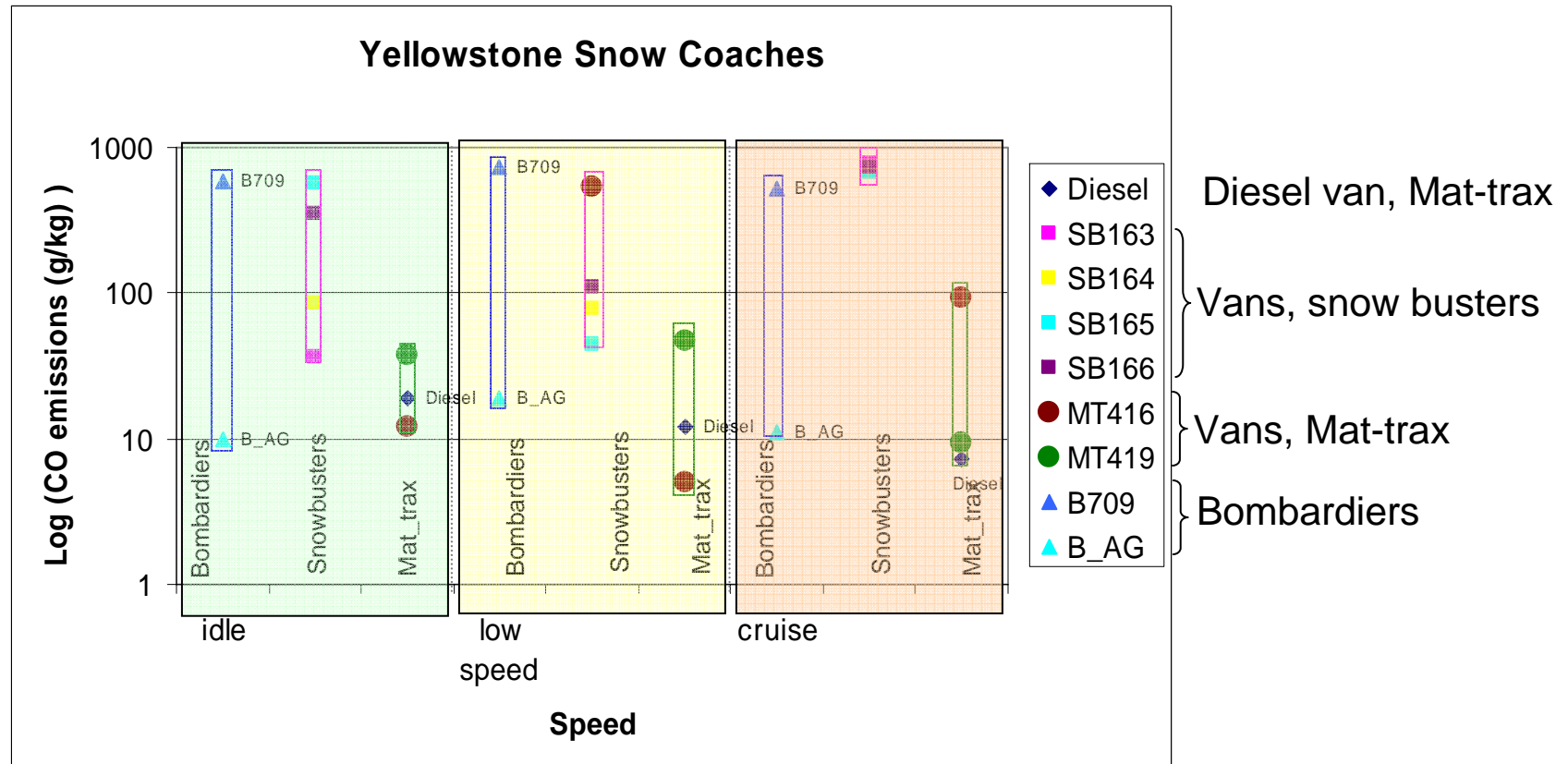
Snow Coach Emissions

					Mean	Emissions (gm/mile)			
Vehicle	Type	Engine	Fuel control	Tracks	MPG	CO	HC	NO	PM
NPS Van	Diesel van	7.3 L V-8	fuel injection	Mat-Trax	3.1	7.0	--	48.0	0.1
Xanterra	gasoline van	5.7 L V-8	fuel injection	Snow buster	3.5	490.0	13.3	21.5	--
Xanterra	gasoline van	8.1 L	fuel injection	Mat-Trax	3.0	46.7	1.2	21.0	--
Xanterra	Bombardier	5.7 L V-8	carburetor	Twin Tracks	3.6	630.0	50.0	7.7	--
Alpen Guides	Bombardier	5.7 L V-8	fuel injection	Twin Tracks	6.8	5.3	1.0	1.4	--

Highest CO and HC emissions are from the snow buster conversion vans and the old Bombardiers.

Cleanest was an updated Bombardier with modern emission controls.

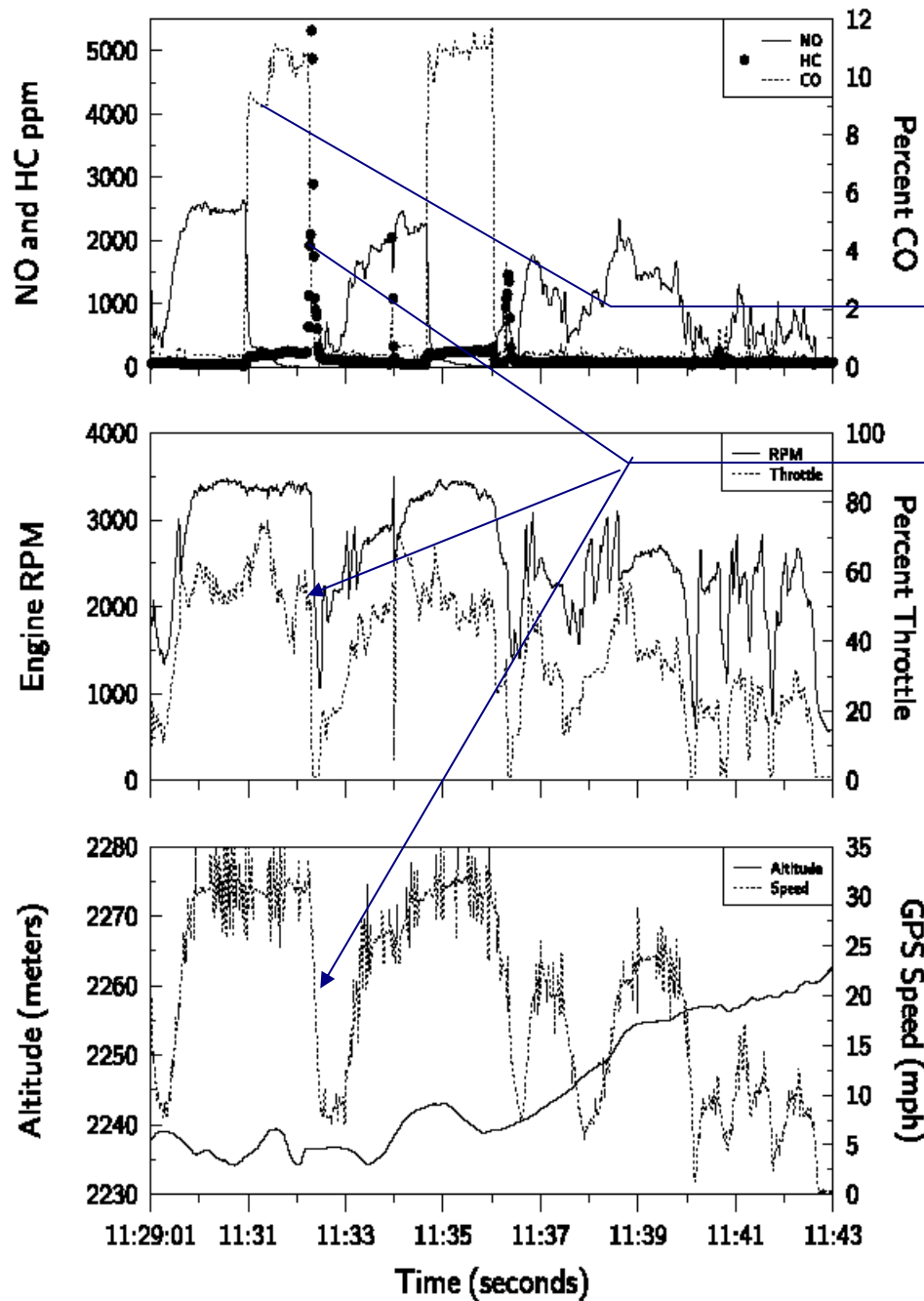
Snow Coach Emissions



Data can be broken out into different snowcoach types and travel speeds.

Large range on emissions (note log scale)

Winter Vehicles Emissions



Example of off-cycle operation by conversion van as it approaches Old Faithful on Feb 9, 2005.

High load: CO high and NO low, HC increased. Rich combustion zone; Off-cycle operation

Rapid deceleration results in HC "puff"

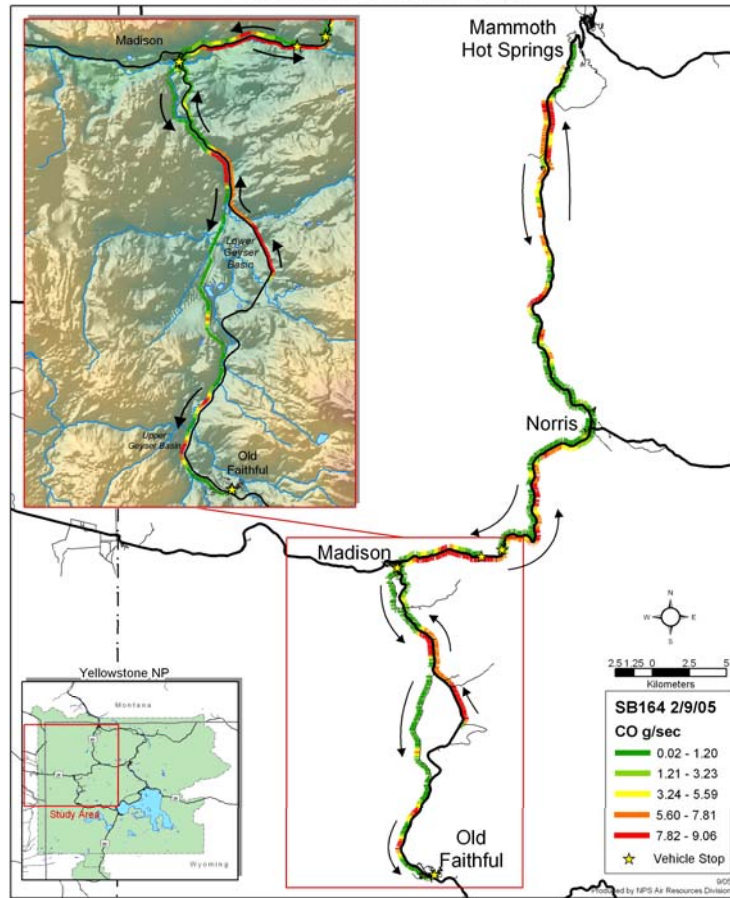
SB 164 snowbuster, 1992 van

Emissions (gm/mile)

	CO	HC	NO	PM
This segment	330.0	4.10	19.0	--
Average inbound trip	350.0	4.80	26.0	

Snow Coach Emissions Study

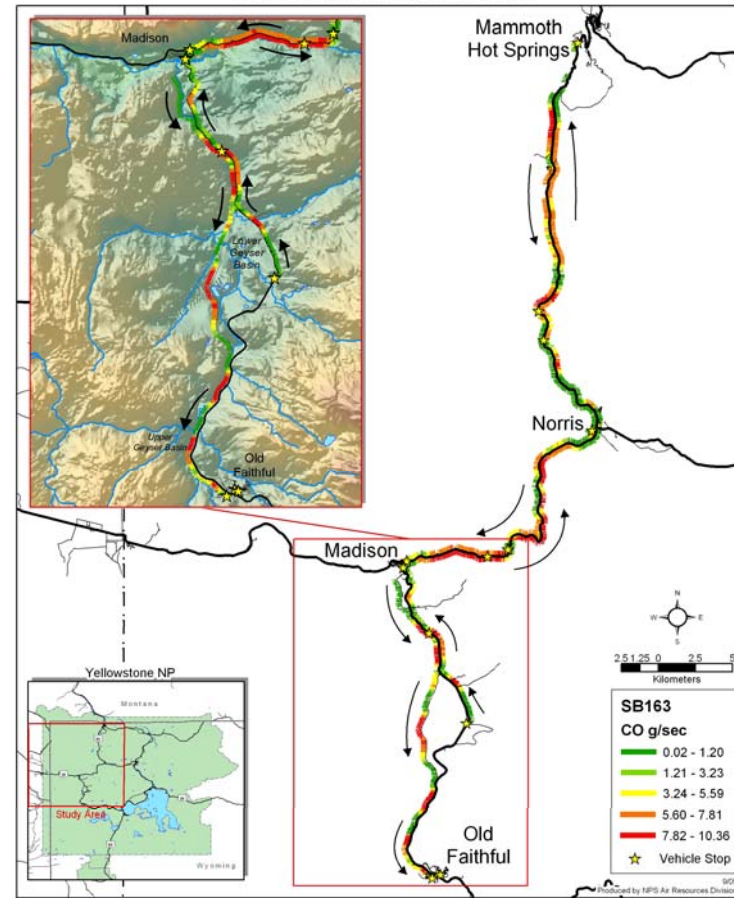
Snowbuster 164 Emissions 2/9/05 - CO g/sec
One Minute Rolling Average



Emissions (gm/mile)

CO	HC	NO	PM
450.0	6.30	19.0	--

Snowbuster 163 Emissions 2/15/05 - CO g/sec
One Minute Rolling Average



Emissions (gm/mile)

CO	HC	NO	PM
600.0	7.20	26.0	--

Winter Vehicle Emissions Comparisons

Emissions in g/mile/passenger

	Snowmobile ¹			Snowcoach ²	
Pollutant	2-stroke	4-stroke	Cleanest	Average	Cleanest
CO	65	28	24	42	0.7
HC	81	3.4	3	1.7	0.1
NO	- -	2.4	2	3.1	0.2

¹ Average snowmobile passenger load of 1.3

² Average snow coach passenger load of 8.0

Based on current passenger load factors, the snowmobiles and snowcoaches are nearly equal in emissions. Presently, the 4-stroke snowmobiles have a slight edge in lower CO.

Snowcoaches have the potential to be the cleaner transport mode.

Summary Results

- Snowmobile emissions are lower for 4-stroke sleds
 - CO reduction is 40-60%
 - HC reduction is >95%
- Snowcoach emissions are larger per vehicle, but about equal on a per passenger basis for the fleet average.
 - large variation in snowcoaches
 - tons/year estimates nearly equal
- Several snowmobile surprises:
 - Ski Doo's had little CO reduction with 4-stroke engines
 - Emissions in g/mi did not increase with speed
 - Re-started sleds have higher emissions in gate area

